Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Influence of Well Yield Changes on Qualitative Parameters of Geothermal Water

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Keywords: Geothermal water, well yield changes, chemical composition, gas content, overexploitation

ABSTRACT

The change in geothermal water exploitation (replacing of the free outflow by increased pumping) could cause unwished changes in geothermal water properties and consequently also some technological problems during utilization and liquidation of the used geothermal water. In the end, the long-term overexploitation of geothermal water could influence not only a single geothermal well, but consequently, the whole geothermal structure.

Influence of well yield changes was studied on the example of geothermal well VZO-13 Zlatna na Ostrove (Slovakia) located in the central depression of the Danube Basin. Qualitative properties of geothermal water exploited by free outflow of 7.5 l/s were compared with those, exploited by pumping with the rate of 18.33 l/s. The value of TDS has increased from 2.5 g/l to 13 g/l. The change was accompanied by changes in gas composition and content. The total gas content increased from 274 l/m^3 to 1117 l/m^3, nitrogen content decreased from 20 l/m^3 to 1.8 l/m^3, CO_2 content increased from 15 l/m^3 to 57 l/m^3 and the methane content increased from 239 l/m^3 to 1058 l/m^3. The change in gas content resulted in the change of bubble point depth which decreased from 150 m (by the free outflow of 7.5 l/s) to the depth of 250 m below the surface (by the pumping rate of 18.33 l/s). Hydrodynamic calculations also documented that by the long-term abstraction of the 18 l/s, the free outflow will disappear and the piezometric head of geothermal water will decrease to the depth of 85 m below the surface.

1. INTRODUCTION

Increasing energy prices lead to more intense utilization of renewable energy sources, among them also to more intense use of geothermal energy. Therefore the free outflow from geothermal wells is often replaced by pumping of geothermal waters using submersible pumps in order to increase the water amount for energy supply.

Excessive increase of the abstraction of geothermal water amounts from wells is quite often at present. The over-exploitation might cause unwished changes in qualitative parameters of geothermal water. They could be manifested by changes in mineralization (TDS) value because of changes in cation and anion composition of geothermal water. At the same time, changes in gas composition and content occur in both – dissolved and free gaseous phases consequently leading to change of the bubble point depth.

The multilayer artesian environment of Neogene sediments in Slovakia is quite sensitive on the abstracted amount of geothermal water from a well. Different chemical types of geothermal water are stored in aquifers at different depth. Changes in chemical composition of geothermal water by different abstracted yields were studied on the example of the well VZO-13 Zlatna na Ostrove.

2. STUDIED AREA

The central depression of the Danube Basin is situated in the southern part of the Slovak Republic, being the continuation of the large Pannonian basin. It is delineated by the Danube River in the southwest between the cities of Bratislava and Komarno, by the Male Karpaty Mountains in the northwest, by the Dobra Voda fault in the northeast, and approximately by the Nitra River in the southeast.

2.1 Hydrogeothermal Conditions in the Central Depression of the Danube basin

A crystalline complex (schists, granitoids) has been identified in the pre-Tertiary base of its north-western and south-eastern part. According to the geological development of the Danube Basin it can be assumed that the whole pre-Tertiary base of the central depression is formed by the Carpathian crystalline. Therefore, there are no suitable sources of geothermal water in the pre-Tertiary base (Franko et al., 1995). The depression is filled with the Quaternary and Rumanian gravels and sands, and mixtures of clays or sandy clays and sands to sandstones (Dacian, Pontian and Pannonian). The depression developed between the Pannonian and Pliocene ages and is of a brachysynclinal shape, with the deepest part in the area of Gabcikovo. The situation of geothermal wells in the central depression of the Danube Basin is shown in Figure 1.

The reservoir of geothermal water is overlain by 1000 m of surface deposits. It is contained laterally and below by a relatively impermeable base with predominant clays (aquiclude) which dips from all sides into the centre where the reservoir probably lies at a depth of 3400 m (FGGa-1 borehole). The main geothermal aquifer is formed by Pannonian and Pontian sands and sandstones. In the central part of the depression, geothermal aquifers are also formed by Dacian sands and sandstones. Clays act as an aquiclude (Remsik et al., 1990).

Totally 40 wells were drilled until present in the central depression of the Danube Basin. The well depths range between 306 m and 3303 m, the yield between 0.1 – 25.0 l/s. The temperature at the wellhead has the value between 19 °C and 91 °C, and the mineralization between 0.5 and 18.6 g/l.

Based on the research performed in the central depression of the Danube Basin until now, the genesis and spatial distribution of the geothermal water chemical composition is dependent on the depth, however, with some specifics. The synclinal structure of the central depression causes that the mineralization (TDS) gradient on the edges of the structure is higher than in the centre, but it always increases with the depth.

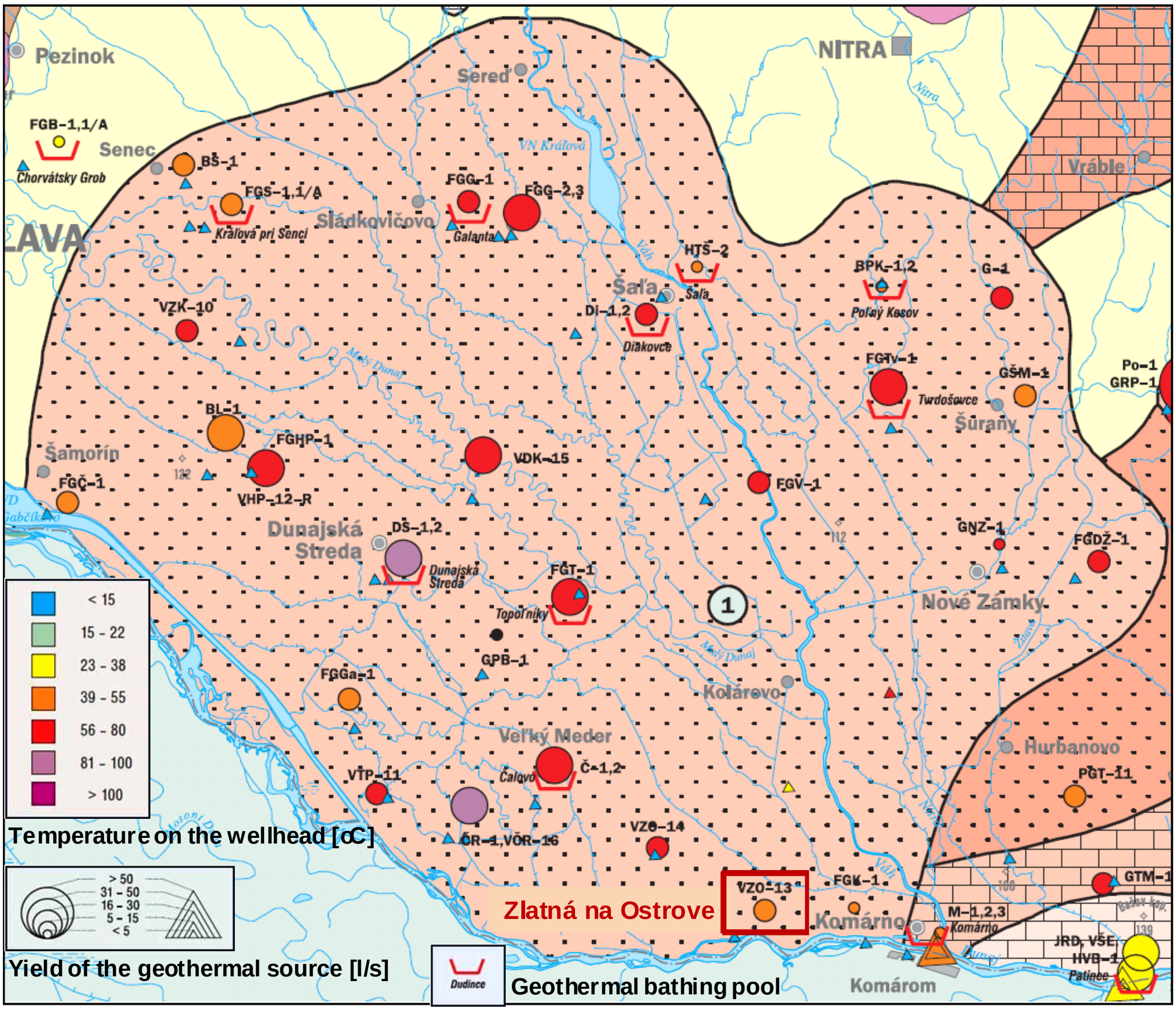

Figure 1: Location of geothermal wells in the central depression of the Danube Basin (Fendek et al. in Landscape Atlas of the Slovak Republic, 2002)

In contrary, content of the sodium-bicarbonates compound (A_1), calculated according to classification of Gazda decreases with the depth, together with the value of geochemical factor HCO_3/Cl. The sodium-chloride compound ($S_1(Cl)$) increases with the depth. These regularities are underpinned also by the light oxygen isotope content which values increase with the depth approaching the average value of the oceanic water. Vertical and horizontal zoning of the chemical and isotopic composition of the geothermal water manifests itself also by gradual desalinization of the sedimentary area. It can be stated, that up to the depth of about 1500 m at the edge and up to 2000 m in the center, the original waters are replaced by meteoric (precipitation) water (Fendek and Bodis, 1992).

According to gas composition, geothermal waters of the central depression of the Danube Basin are of methane, nitrogen, methane-nitrogen, or methane prevailing type. The highest methane content is typical for waters of sodium-chloride type, the methane content increases with the depth. Carbon dioxide dominates among the acid gases, being bounded to the higher parts of the structure. Methane dominates in the free gaseous phase, carbon dioxide in the dissolved gaseous phase.

2.2 Location and Basic Parameters of the Well VZO-13

Geothermal well VZO-13 is located in the south-eastern part of the central depression, 1500 m to the east of the village Zlatna na Ostrove. The well was drilled in 1988 by rotary system up to the depth of 1780 m and cased to the depth of 1650 m. It was planned to use the geothermal water the whole year round. Within the heating season, greenhouses and glasshouses should be heated; out of the season, the thermal energy should be used for drying of agricultural products.

The first hydrodynamic measurements were accomplished in the period of 1988 – 1990 and they were summarized in the final report of Dzurik et al. (1991). Next measurements were done by VIKUV Rt, Budapest in the period 14.2.2006 – 16.2 2006 and they were summarized in the technical report of Gyurusi (2006). Results of both series of hydrodynamic measurements were used for elaboration of this paper.

The drilled perforation of 7“ diameter was installed in the depth interval of 1090 – 1625 m. Six sections with the total thickness of 251 m (minimum thickness of 12 m, maximum of 96 m) were cased. Geothermal water aquifers are built by sandy sediments of Pannonian and Pontian ages. The recommended yield was 7.5 l/s of geothermal water of Na-

Cl type with the temperature on the wellhead of 51 °C and mineralization of 2.5 g/l (Dzurik et al., 1991). Methane, nitrogen and carbon dioxide gases were present.

3. RESULTS AND DISCUSSION

Assessment of deep sampling chemical and isotopic analyses, as well as evaluation of pressure conditions changes in the well at different yields brought following results.

3.1 Changes in Chemical Composition and Mineralization

Sampling of geothermal water from different sections in the well VZO-13 was performed during the period 1988 – 1990. The increase of mineralization from 2.2 to 13.3 g/l was documented. The total gas content increases from 274 l/m^3 to 1117 l/m^3, whereby nitrogen content decreased from 20 l/m^3 to 1.8 l/m^3, content of CO_2 increased from 15 l/m^3 to 57 l/m^3 and distinct increase of methane content from 239 l/m^3 to 1 058 l/m^3 was proved. The methane content fits best the total gas content, as it can be seen in Figure 2.

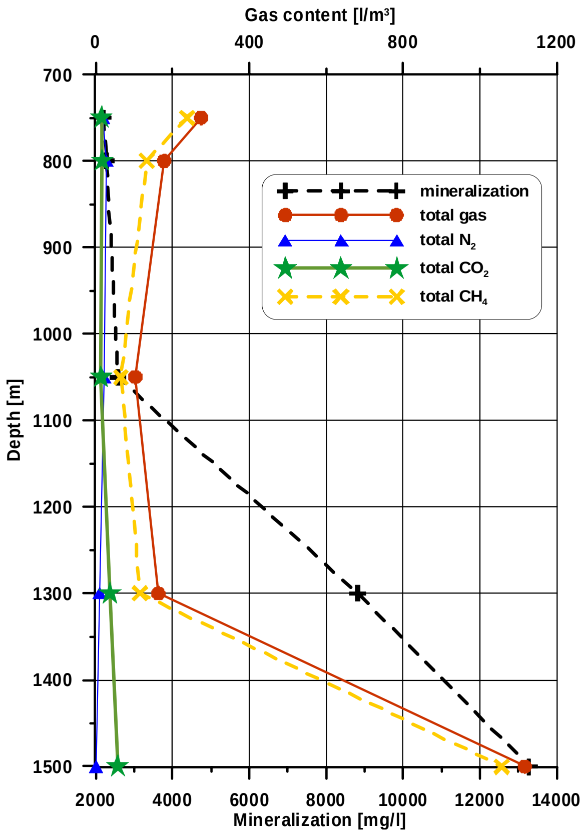

Figure 2: Change in mineralization and gas content with the depth

Such vertical changes indicate that the chemical composition, mineralization, total gas content and composition is going to be dependent on distribution of inflows into the well, as it results from Figure 2.

Figure 3 shows the distribution of inflows into the geothermal well VZO-13 estimated by flowmetry measurements.

There were temperature gradient measurements done in 1988 – 1990 and 2006. Therefore results of flowmetry in Figure 3 are drawn together with the temperature gradient measured at the well yield of 7.4 l/s in 1990 and at the well yield of 26.16 l/s measured in 2006.

As it can be seen in Figure 3, almost all well yield (about 80 %) came from the inflows from the first well screen section at the depth interval of 1090 – 1180 m. Mineralization and gas content are distinctly lower in this section. At the depth of 1 050 m, the mineralization has the value of 2.58 g/l and the gas content the value of 104 l/m^3. No inflows into the VZO-13 well were proved at the well yield of about 8.0 l/s (1988 – 1989) from the last three well screen sections located at the depth intervals of 1450.2 – 1462.5 m; 1474.4 – 1486.2 m and 1529.9 – 1625.0 m on which geothermal waters with the higher mineralization and gas content are bound. The mineralization at the depth of 1500 m reaches 13.28 g/l and the gas content has a value of 1117 l/m^3.

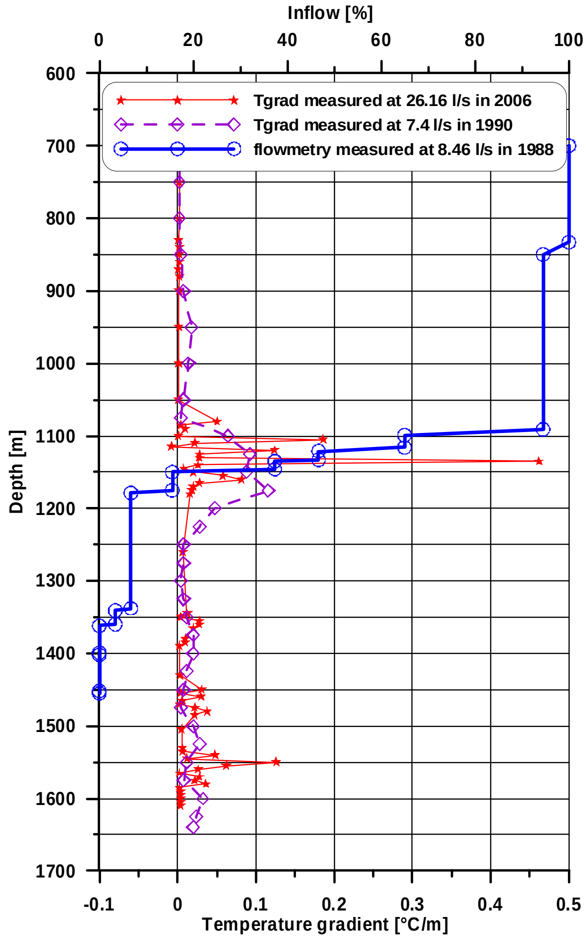

Figure 3: Course of yield and temperature gradient in geothermal well VZO-13

Evidence of the inflow into the well from the level of 9$^{5/8}$“ diameter casing overlapping with the 7“ diameter casing at the depth interval of 850 – 904 m was also an interesting result of the evaluation. The inflow from behind the 7“ diameter casing made about 4 – 5 % of the total well yield, contributing to lowering of the total mineralization and gas content values. This can be seen also from the temperature gradient values measured from the temperature profile at the well yield of 7.4 l/s in 1990. This makes it possible to inter-connect inflow measurements with the temperature change. It is evident that through the temperature gradient, the inflow changes into the well could be assessed.

No flowmetry was done during the series of measurements performed in the well VZO-13 in 2006; however, the temperature profile was measured at the well yield of 26.16 l/s. The temperature gradient at this yield has a different course as it used to have at the well yield of 7.4 l/s (Figure 3). The main difference consists in indication of the inflow to the well from the depth of about 1550 m, e.g. from the lowest well screen section (1529.9 – 1610 m). This was proved also by higher mineralization (11.7 g/l) estimated for geothermal water sample taken at the well yield of 18.33 l/s. The mineralization change together with the change in well yield is showed in Figure 4.

Figure 4 shows that the distinct decrease in mineralization starts with the yield value of about 10 l/s. The mineralization values between 2 – 3 g/l could be expected with the yield values being below 10.0 l/s.

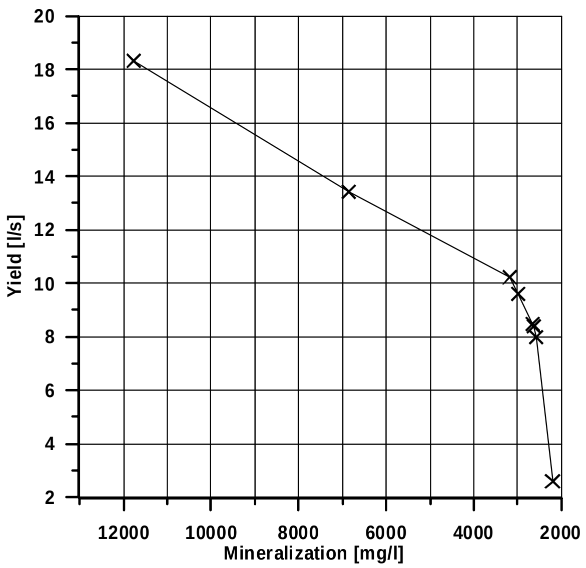

Figure 4: Relationship of mineralization and the well yield

On contrary, the values of mineralization from 3.0 g/l to 13.0 g/l and more could be expected in the well VZO-13 by the well yield higher than 10.0 l/s. The chemical composition and chemical type of geothermal water in the well shall change with the mineralization value, too. Table 1 shows the change in chemical type at different yield values. Chemical type of water classified as Na-Cl basic, not distinct, was estimated at the lowest yield of 2.6 l/s (mineralization of 2.19 g/l). At the yield of 7.9 l/s and higher (mineralization values 2.56 g/l and more) the chemical type of water was classified as Na-Cl basic, distinct type.

The content of sodium-bicarbonate compound (A_1) decreases with higher mineralization of geothermal waters, the same is valid for the geochemical factor HCO_3/Cl. The content of sodium-chloride compound ($S_1(Cl)$) increases. The value of the genetic coefficient HCO_3/Cl could be used for classification of a geothermal structure. The value of the coefficient HCO_3/Cl at the well yields from 2.6 l/s to 10.2 l/s (Table 1) characterize a semi-closed geothermal structure, values estimated for the well yield of 13.4 l/s and more are typical for the closed structure of geothermal water from which the inflow into the well is realized.

3.2 Change in Gas Content

Hydrogeothermal conditions in Slovakia (depth of geothermal aquifers, pressure, reservoir temperature, composition and content of gases) cause one-phase groundwater flow in reservoir conditions. This could change during exploitation of geothermal water by wells. There is a distinct change in pressure conditions during the upwards flow of geothermal waters from the reservoir towards the wellhead and part of the dissolved gas changes into a free phase. The change can be seen on the course of the gradient of dynamic values of the hydrostatic pressure (Fendek, 1993).

Increase of dynamic values of the hydrostatic pressure depends first of all on the depth interval and the measured values have a straight-line course in the case of a homogeneous liquid. When the measurement errors could be excluded, the deviation from the straight-line course could be caused by inhomogeneity occurrence, resulting from the change of liquid specific weight along the vertical profile of a well (Fendek, 1992). Gradient of hydrostatic pressure, calculated from the data on vertical change in dynamic values of the hydrostatic pressure, was used in the first step for inhomogeneity identification. Gradient values were measured at the yields of 8.07 l/s (in 1989) and 18.33 l/s (in 2006) in the well VZO-13 (Figure 5).

As it can be seen in Figure 5, values measured in 1989 at the yield of 8.07 l/s do not show any principal deviation from e straight-line course and vary in the interval 9.5 – 10.0 kPa/m. The course of values measured in 2006 at the yield of 18.33 is different. At the depths from 175 m to 800 m the gradient of dynamic values of the hydrostatic pressure changes in the same interval of 9 – 10 kPa, as in 1989, but upwards from the depth of 175 m the course changes principally. The gradient values regularly diminish, what is evidence on decrease of the specific weight of geothermal water due to free gas content. Free gas loosing is accompanied by bubbles origination.

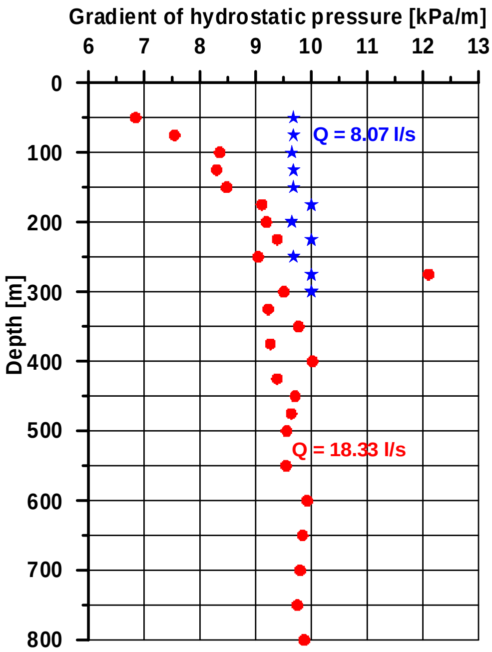

Figure 5: Course of the gradient of hydrostatic pressure hydrodynamic values in the geothermal well VZO-13 at different yields

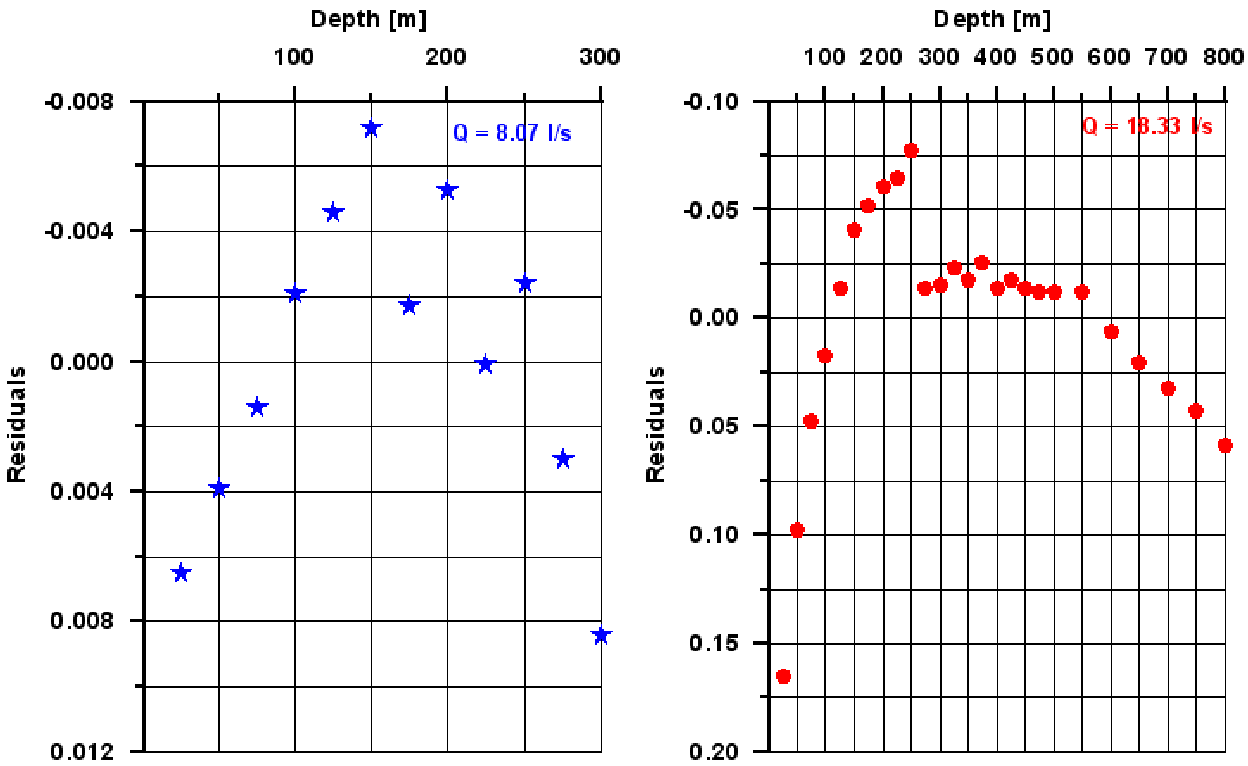

Fig.6. Course of residuals for geothermal well VZO-13 at the yield of 8.07 l/s (left) and 18.33 l/s (right)

Dynamic values of hydrostatic pressure could be used for estimation of the bubble point depth by analysis of residuals of a regression relation (Fendekova – Fendek, 1993). Utilization of this method removes uncertainty of bubble point depth estimation which is typical for some other methods often used for this purpose.

Residuals of dynamic values of hydrostatic pressure plotted against the depth are showed in Figure 6. The same measured values as those showed in Figure 5 were used. Values of residuals in Figure 6 (left and right) decrease in the beginning and reach the minimum (turning point) in the bubble point depth.

Bubble point calculated using residuals analysis method was estimated at the depth of 150 m for the yield of 8.07 l/s (measurements from 1989, Figure 6 left.) and at the depth of 250 m for the yield of 18.33 l/s (measurements from 2006, Figure 6 right). Residual values start to grow from the depth of 150 m, and 250 m respectively.

Taking into account changes in mineralization and gas content (Figure 2), different values of the bubble points at different yields (Figure 6) offer the possibility to make another conclusion on increase of gas content in geothermal water. The increase in gas content results in the decrease of bubble point to larger depths at higher yields.

The influence of gas composition and content on the bubble point is showed in Table 2. The calculation was based on existing results of gas analyses for the well yield of 18.33 l/s (samples 1 – 4) and for the well yield of 8.5 l/s (sample 5 in Table 2.). Labeling p_{ri} is used for the real instantaneous static value of the pressure on wellhead.

Calculated values of the bubble point depths, depending on the gas content (0.274 – 0.662 m^3/m^3) and gas composition given in Table 2, vary in the range of 110 – 336 m. The bubble point depth of 110 m for the well yield of 8.5 l/s is in a good accordance with the value estimated using residuals analysis method (150 m, Figure 6) and similarly, the depth of 235 m for the well yield of 18.33 l/s (250 m, Figure 7). Results confirmed the assumption of the bubble point decrease towards the larger depths with the increasing gas content.

The pressure at the wellhead (sample 4) for the total gas content of 0.662 m^3/m^3 has been increased to increase the counter-pressure, to be able to see its effect on the bubble point depth. The bubble point depth changed from the value of 336 m at the pressure of 0.014 MPa at the wellhead on 210 m at the pressure of 1.0 MPa, and, at the same time, the negative value of the real instantaneous static value of the pressure at the wellhead was reached (Fendek, 1989).

When comparing the real instantaneous static value of the pressure at the wellhead (p_{ri}) of the geothermal well VZO-13 (from -0,833 up to +0,400 MPa, Table 2) with the depression (p_m) measured at the depth of 1050 m during the free outflow test at the yield of 8 – 26 l/s (0.249 – 0.555 MPa), the disproportion between measured depression and calculated depressions is visible. Calculated values of the real instantaneous static values of the pressure at the wellhead in the first two cases – sample 1 and 2 (0.244 and 0.298 MPa) are in a very good accordance with the depression value measured at the yield of 8 l/s (0.249 MPa). In the third case (sample 3) its value (0.4 MPa) approaches the values measured at the yield of 26.16 l/s (0.555 MPa), but the difference is still considerable. The difference could be caused either by a wrong depression measurement or by the low gas content.

The negative value of the real instantaneous static value of the pressure at the wellhead (sample 4) is the result of the decrease of water level below the wellhead expressed in pressure units. It means that by long-term pumping of the excessive amount of geothermal water (18.33 l/s) the water level in the well VZO-13 shall vary around the level of 85 m below the surface.

3.3 Gaslift and Thermolift Changes

Change in gas amount caused by the change in the well yield manifests itself consequently by changes in measure of influence of the free gas content and water temperature on the measured depression p_m in the geothermal well.

Calculation results of the influence of free gas content (gaslift) and temperature (thermolift) on the measured depression value are given in Table 3. It shows that the highest values of the gaslift (0.271 MPa) were calculated for maximum values of the free gas content of 0.662 m^3/m^3 (gas sample No. 4, Table 2). The share of the gaslift on the measured depression is 21 – 50 %. Low influence of gaslift – only 5 % (sample No. 4, Table 3), shows the suppressing of the free gas influence by increasing the pressure at the wellhead.

Thermolift according to stable temperature conditions in the well at the constant yield has an almost constant value of about 0.105 MPa, which makes about 19 % from the total measured depression. The thermolift value at lower yield of 8.5 l/s reaches up to 53.4 %.

Based on the total influence of the gaslift and thermolift it can be concluded that from the point of view of a long-term exploitation, the well yield of the geothermal well VZO-13 at the rate of 18 l/s cannot be secured by the free outflow.

4. CONCLUSION

Excessive increase of the abstraction of geothermal water amounts from wells situated in the central depression of the Danube Basin could cause the unwished changes in qualitative parameters of geothermal waters. They could manifest themselves by changes in the value of mineralization because of changes in cation and anion composition of geothermal water. The reason could be in increased inflows from the lower sections of well screens, reaching the horizons with original waters of marinogene mineralization, typical for closed geothermal water structures. At the same time, changes in gas composition and content occur in both – dissolved and free gas phases, consequently leading to change of the bubble point depth.

Increase of well yield in geothermal well VZO-13 Zlatna na Ostrove from the value about 8 l/s to 18.33 l/s caused the increase of mineralization from 2 – 3 g/l to more than 13 g/l with the change in chemical composition and type of geothermal water. The changes were accompanied by the change in the gas content and composition. Nitrogen gas content decreased importantly, the multiple increasing in carbon dioxide and mainly in the methane content was proved. Consequently, the bubble point depth decreased in 100 meters.

All mentioned changes in qualitative parameters of geothermal water consequently could cause the need of technology changes by their utilization. Such technological changes can also be connected to higher economic pretention of use and liquidation of geothermal waters.

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Table 1: Chemical composition of geothermal water in the well VZO-13 at various yields

Sampling date	Yield [l/s]	Mineralization [g/l]	S_1(Cl) compound	A_1 compound	HCO_3/Cl coefficient
15.02.2005	18.3	11.77	92.33	0.00	0.03
27.10.1989	13.4	6.85	84.81	0.41	0.09
07.11.1989	10.2	3.17	75.18	17.44	0.33
05.01.1990	9.6	2.98	72.15	21.28	0.38
04.12.1989	8.4	2.64	68.71	24.30	0.45
19.12.1989	7.9	2.56	68.50	24.49	0.46
15.01.1990	2.6	2.19	63.24	30.25	0.58

Table 2: Change in the bubble point depth depending on gas content and composition

Gas sample	Sampling date	Yield [l/s]	Pressure at the wellhead [MPa]	Gas content [m^3/m^3]				Bubble point [m]	P_{ri} [MPa]
				N_2	CH_4	CO_2	total		
1	15.02.2005	18.33	0.014	0.005	0.323	0.035	0.363	167	0.244
2	23.01.1990	18.33	0.014	0.020	0.415	0.019	0.454	235	0.298
3	22.01.1990	18.33	0.014	0.016	0.605	0.041	0.662	336	0.400
4	22.01.1990	18.33	1.000	0.016	0.605	0.041	0.662	210	-0.833
5	23.01.1990	8.50	0.050	0.020	0.239	0.015	0.274	110	0.189

Table.3. Comparison of gaslift and thermolift values with the measured depression p_m for various yields

Gas sample	Date	Yield [l/s]	Depression p_m [MPa]	Gaslift		Thermolift	
				[MPa]	[%] from p_m	[MPa]	[%] from p_m
1	15.02.2005	18.33	0.555	0.116	20.9	0.105	18.9
2	23.01.1990	18.33	0.555	0.170	30.6	0.106	19.1
3	22.01.1990	18.33	0.555	0.271	48.8	0.108	19.4
4	22.01.1990	18.33	0.555	0.028	5.0	0.105	18.9
5	23.01.1990	8.50	0.249	0.053	21.2	0.133	53.4